Nuclear Structure Study of ^{106}Pd with the Inelastic Neutron Scattering Reaction

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Introduction

Multiphonon vibrational excitations in **spherical nuclei** have been studied for many years. Much of the discussion has focused on the **quadrupole phonon** excitations and information regarding the **octupole-coupled phonon** states is less available.

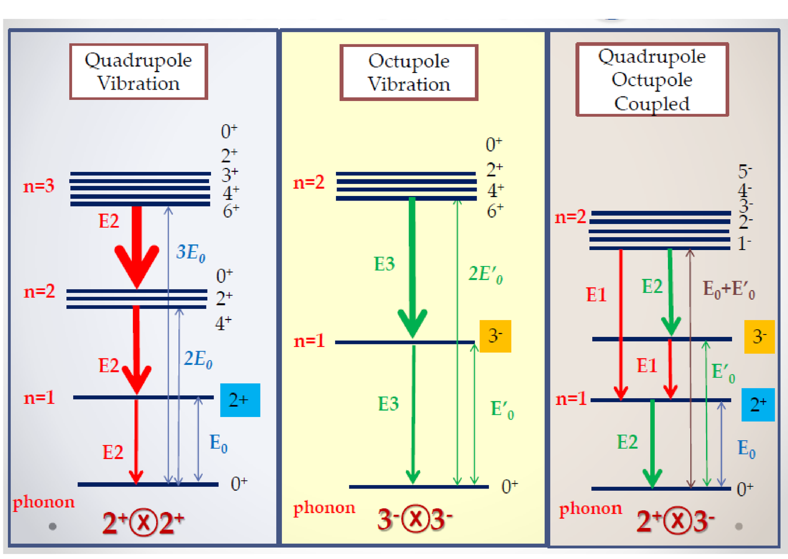


Fig.1. Quadrupole, octupole and quadrupole-octupole coupled vibrational spectra, respectively. The arrows are proportional to the expected transition strength.

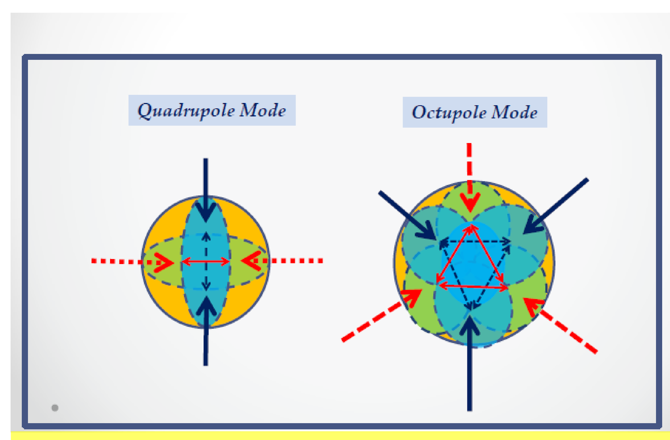


Fig. 2. Schematic representation of the time evolution of the quadrupole and octupole vibrational modes.

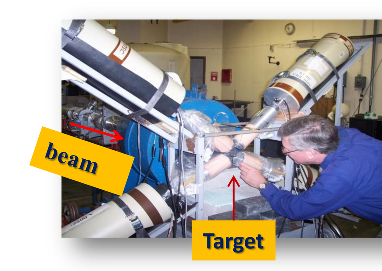
Is ^{106}Pd the best harmonic vibrator?

The ^{110,112,114}Cd and ^{106,108,110}Pd isotopes have been considered as the best example of harmonic spherical vibrators. In recent studies of the Cd isotopes[1,2,3], serious discrepancies from the vibrational decay pattern were found, suggesting a breakdown of the quadrupole vibrational picture. Coulomb excitation studies of ^{106,108}Pd [4] show that the quadrupole vibrational degree of freedom is important for the description of the low–spin level structure of these nuclei, but they cannot explain the observed decays properties of the two-phonon vibrational states.

[1] P.E. Garrett et al., Phys. Rev. C **75**, 054310 (2005)
[2] D. Bandyopadhyay et al., Phys. Rev. C **76**, 054308 (2007)
[3] M. Kadi et al., Phys. Rev. C **68**, 031306(R) (2003)
[4] L. E. Svensson et al., Nucl. Phys. **A584**, ??? (1995)

Experimental Set-up

University of Kentucky 7-MV Van de Graaff accelerator.
Monoenergetic neutrons: ^{3}H(p,n)^{3}He



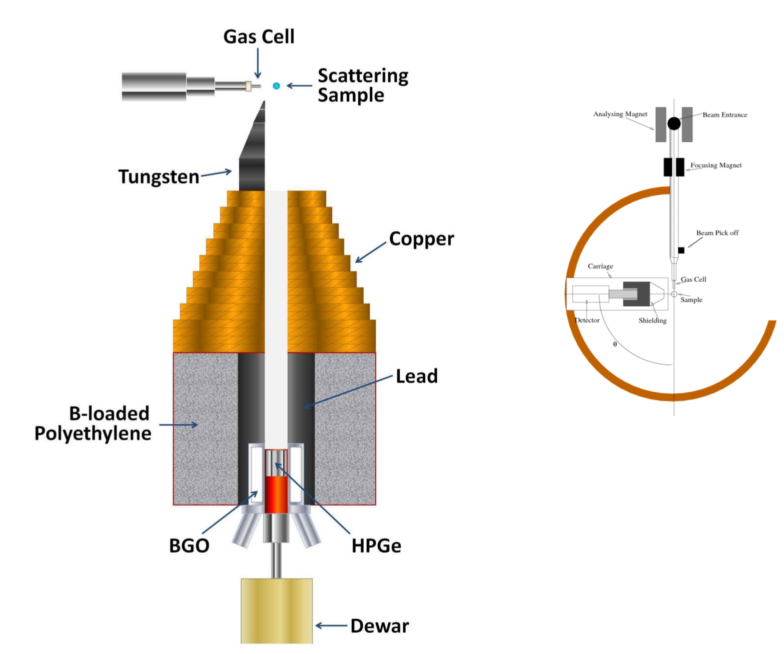


Fig. 3. Experimental set-up used for singles measurements **(n,n'γ):** angular distribution and excitation function

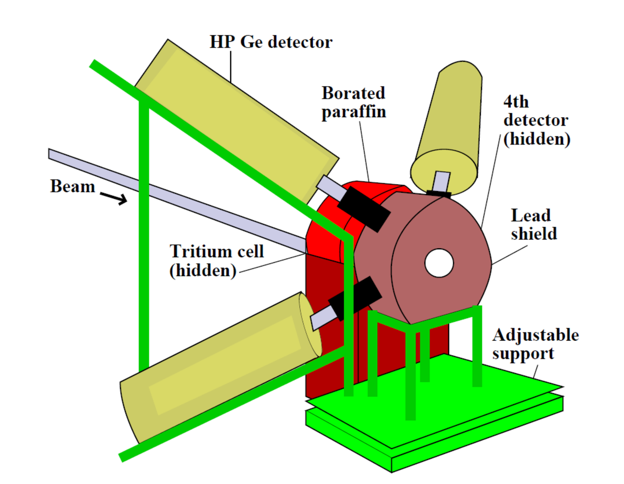


Fig. 4. Experimental setup for **(n,n'γ γ)** coincidence measurements with four **HPGe** detectors. The relative efficiencies of the detectors are between 52% and 57%.

Experimental Analysis

Excitation functions where γ-ray yields were obtained at E_n= 2.0 to 3.8 MeV in 0.1-MeV steps. Angular distribution measurements with E_n=2.2, 2.7 and 3.5 MeV; spectra recorded at angles from 40º to 150º.

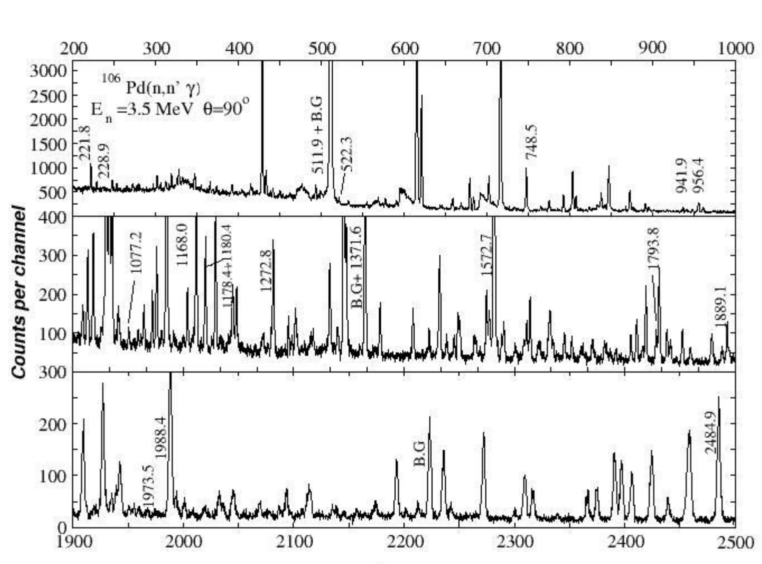


Fig.5. γ-ray spectrum obtained in the ^{106}Pd(n,n'γ) reaction at an energy of 3.5 MeV and a detection angle of 90º (angular distribution 3.5 MeV). The quadrupole-octupole transitions are labeled with energies in keV.

Doppler-Shift Attenuation Methods (DSAM)
Range of lifetimes: 1 fs (10^{-15} s) to ~2 ps (10^{-12} s)[5]

$$E_\gamma(\theta) = E_0\left(1+\frac{v_{cm}}{c}F(\tau)\cos\theta\right)$$

[5] T. Belgya, et al., Nucl. Physics **A500**, 77 (1989)

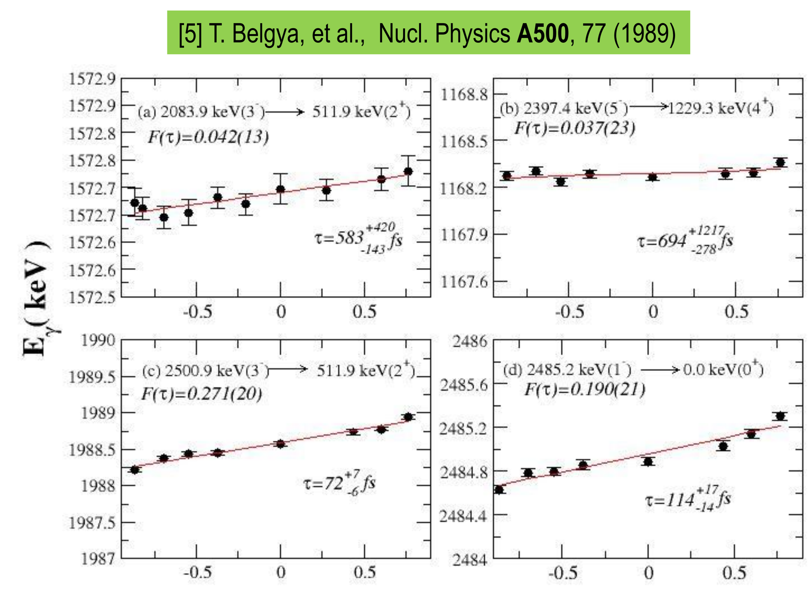


Fig.6. γ-ray energies as a function of cos ϴ for the 1572.7-, 1168.0-, 1988.4-, and 2484-keV transitions. The lines are linear fits to the data, from which the F(τ) values have been obtained

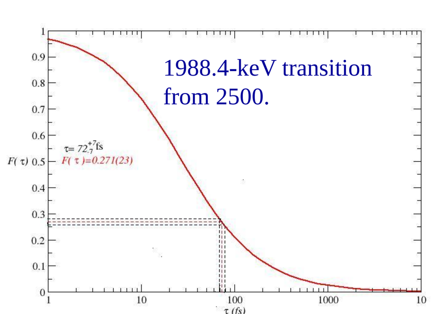


Fig.7. Determination of lifetime by comparison of the experimental F(τ) with those calculated following Winterbon formalism [6].

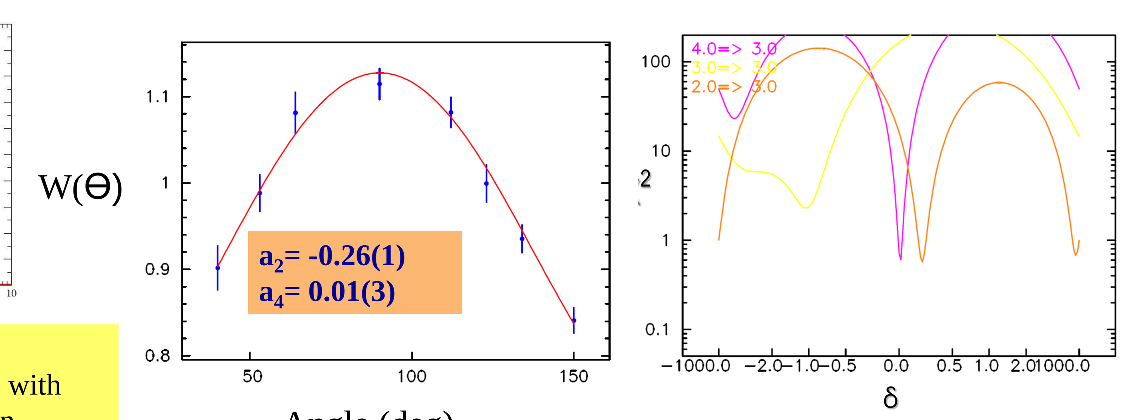
[6] K.B. Winterbon, Nucl. Phys. **A246**, 293 (1975)

Angular distribution data analysis [7]

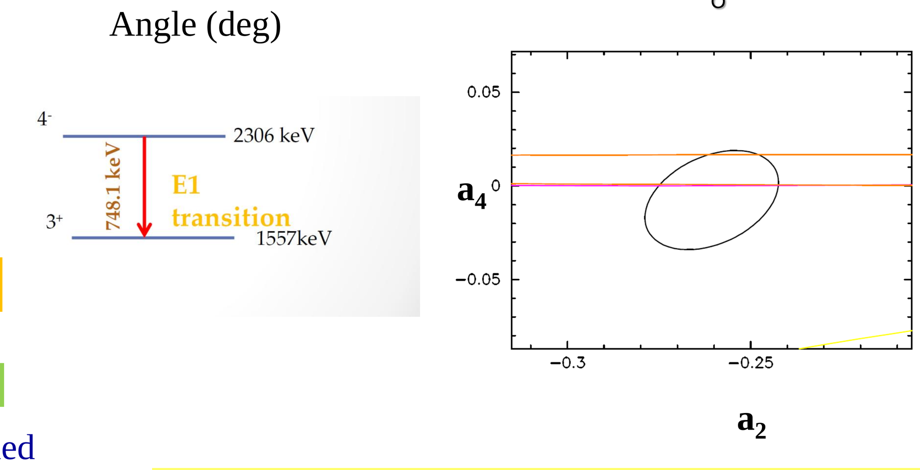
$$W(\theta) = 1 + a_2P_2(\cos\theta) + a_4P_4(\cos\theta)$$

[7] Sheldon and Van Patter, Rev Mod. Phys. **38**, 143 (1968)

The multipole mixing ratio (δ) was obtained from the comparison of the experimental data with the theoretical calculations by a modified version of **CINDY[8].**



Determination the mixing ratio (δ)



Comparison of experimental and theoretical angular distribution coefficients. The spin assignment of 4- for the 2360-keV level is confirmed.

Fig.8. Angular distribution of the 748.4-keV transition from the 2306-keV level (4-). The angular distribution coefficients a_2 and a_4 are in agreement with the typical values of a pure E1(a_2 = -0.2 and a_4≈ 0.0).

[8] Sheldon and V. C. Rogers , Comput. Phys. Commun. **6**, 99 (1973)

Results

- **Lifetimes** have been determined for levels from **2.0 MeV to 3.5 MeV.**
- New **spin assignments** and confirmation of previous spins have been made for the negative-parity states.
- **72 news transitions** have been placed by **the γγ-coincidence analysis**.
- Evidence of **a collective structure for the negative-parity states** has been found (**Quadrupole-Octupole Coupled Structure, see Fig.9**).
- **The analysis is still in progress**.

Quadrupole–Octupole Coupled States in ^{106}Pd

- 2-phonon (Quadrupole)
- 1-phonon (Quadrupole)
- 1-phonon (Octupole)
- quintuplet (Quadrupole-Octupole)

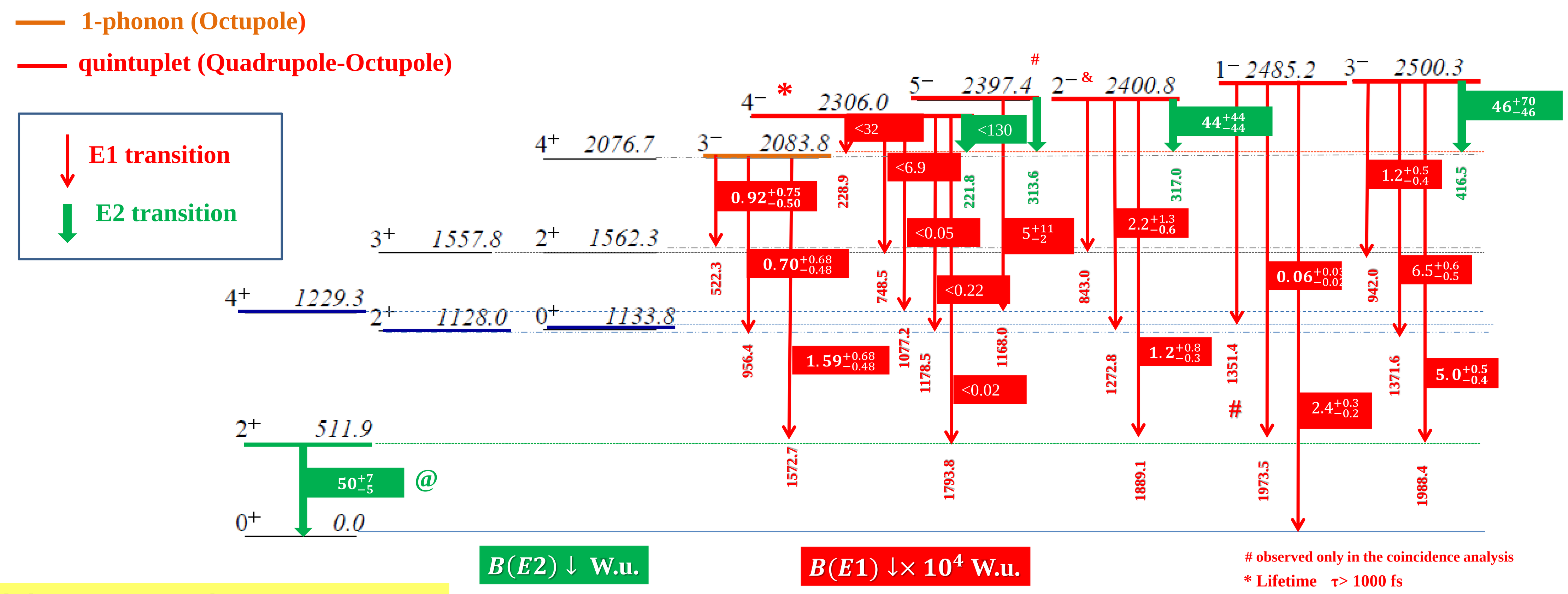


Fig.9. Partial level scheme of ^{106}Pd. The quadrupole-octupole (red) coupled states correspond to excitations between 2.3 and 2.5 MeV. The arrows represent the **E1 (red)** and **E2 (green)** decays that have been observed in **the γγ coincidence** and **singles measurements**. The red and green boxes are the **B(E1)↓ (× 10^4 W.u.)** and **B(E2)↓ (W.u.)** strength, respectively.

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